

MODELLING AND CONTROL OF STANDALONE WIND ENERGY CONVERSION SYSTEM

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ABSTRACT

In this paper, a Wind Energy Conversion System (WECS) is discussed. The power conversion system consists of a Permanent Magnet Synchronous Generator (PMSG), a rectifier and an inverter connected to the grid. An intermediate DC bus exists between the rectifier and inverter. This conversion system use the PMSG because of its high performances, small size and its low weight compared to induction generators. The generator torque is controlled according to the generator speed and thus the power from a wind turbine settles down on the maximum power point by the MPPT control method. Modeling and Simulation of all the components has been done in MATLAB/Simulink.

KEYWORD: Wind energy, MPPT, PMSG, DC-link voltage control

I. INTRODUCTION

In order to overcome the increasing power demand around the world, the use of clean, non-polluting and renewable energy is essential. Wind energy is one the fastest growing sources of electricity. It can decrease the negative environmental impacts of traditional energy sources and reduce the dependency on fossil fuels. Due to their great efficiency, wind energy generation systems could be one of the potential sources of alternative energy for the future.

Wind turbines convert the kinetic energy of the wind to electrical energy by rotating the blades.

PMSGs are widely used in Wind energy application because of their property of self-excitation [1].

In remote areas where power grid is not available, a standalone system becomes an attractive solution. Several countries have substantial renewable energy sources [2]. Local small-scale standalone distributed generation system can utilize these renewable energy resources when grid connection is not feasible.

In this work, a control strategy is developed to control the load voltage in a standalone mode in which the output voltage of load side converter has to be controlled in terms of amplitude and frequency. Section 2 discusses mainly about the description of the wind energy conversion system used in this paper. Section 3 and 4 includes the wind turbine and the permanent magnet synchronous generator models. Control strategies of the generator side and the load side are shown in both sections 5 and 6. Section 7 discusses the results obtained from the MATLAB/SIMULINK of the control technique applied to the wind energy conversion system. Section 8 gives the conclusions of this paper.

II. DESCRIPTION OF THE WIND ENERGY CONVERSION SYSTEM

The system topology used in this article is based in a PMSG, as shown in figure1. This topology shows a better performance compared to the PMSG connected through a diode bridge rectifier and a boost converter to the DC-link for the small and medium power range [3]. This arrangement can be connected to the network or used in isolated areas. Wind Energy is converted into electrical energy and then sent to loads, connected to the grid and/or stored in battery bank. The Wind Energy System contain a variable speed Wind Turbine coupled to a PMSG. The Wind Energy Source is connected to a DC bus through a PWM Rectifier.

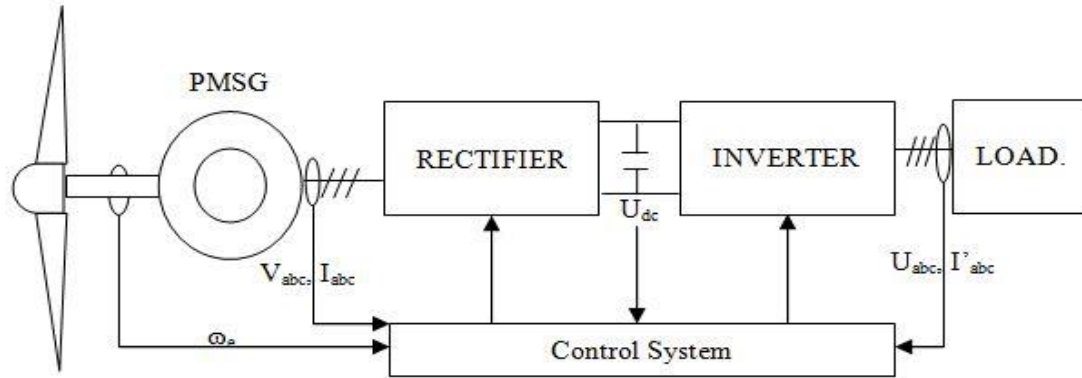


Figure 1: Wind turbine control system

III. PERMANENT MAGNET SYNCHRONOUS GENERATOR MODEL

The rotor excitation of the Permanent Magnet Synchronous Generator (PMSG) is assumed to be constant, so its electrical model in the synchronous reference frame is given by [4, 5]:

$$\begin{cases} \frac{di_d}{dt} = -R_s i_d + V_d + \omega i_q L_q \\ \frac{di_q}{dt} = -R_s i_q + V_q - \omega i_d L_d + \omega \Phi_f \end{cases} \quad (1)$$

where subscripts d and q refer to the physical quantities that have been transformed into the (d, q) synchronous rotating reference frame; R_s is the stator resistance; L_s is the inductances of the stator; V_d and V_q are, respectively, the d and q axis components of stator voltage; i_d and i_q are, respectively, the d and q axis components of stator current; Φ_f is the permanent magnetic flux and the electrical rotating speed ω_e is given by:

$$\omega_e = n_p \cdot \omega_T \quad (2)$$

where n_p is the number of pole pairs. The power equations are given by:

$$\begin{aligned} P &= \frac{3}{2} (v_d i_d - v_q i_q) \\ Q &= \frac{3}{2} (v_q i_d - v_d i_q) \end{aligned} \quad (3)$$

where P and Q are the output active and reactive powers, respectively. The electromagnetic torque T_e can be given by:

$$T_e = \frac{3}{2} n_p \Phi_f i_{sq} \quad (4)$$

IV. WIND TURBINE MODEL

The mathematical relation for the mechanical power extraction from the wind can be expressed as follows [6]:

$$P_m = C_p(\lambda, \beta) \cdot P_w = C_p(\lambda, \beta) \cdot \frac{\rho \cdot A V_w^3}{2} \quad (5)$$

Where P_w is the extracted power from the wind, ρ is the air density [kg/m^3], V_w is the wind speed, A is the area swept by the rotor blades of the wind turbine and C_p is the power coefficient which is a function of both blade pitch angle β and tip speed ratio λ as given by [7],

$$\lambda = \frac{R \times \omega_m}{V_w} \quad (6)$$

where, ω_m is the angular speed of the turbine rotor, and R is the radius of the turbine blades.

The power coefficient C_p can be expressed as [8, 9],

$$C_p(\lambda, \beta) = C_1 \cdot \left(C_2 \cdot \frac{1}{\lambda_i} - C_3 \cdot \beta - C_4 \right) \exp^{(-C_5 \cdot \frac{1}{\lambda_i})} + C_6 \cdot \lambda \quad (7)$$

$$\exp^{(-C_5 \cdot \frac{1}{\lambda_i})} + C_6 \cdot \lambda$$

$$\text{where } \frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1}$$

$C_1=0.5176$, $C_2=116$, $C_3=0.4$, $C_4=5$, $C_5=21$ and $C_6=0.0068$.

The torque of the wind turbine would be expressed as:

$$T = C_p(\lambda, \beta) \cdot \frac{\rho \cdot A V_w^3}{2 \cdot \lambda} \quad (8)$$

V. CONTROL OF GENERATOR SIDE CONVERTER

The generator side control scheme is shown in Figure 2. The Optimal tip speed ratio MPPT method is considered.

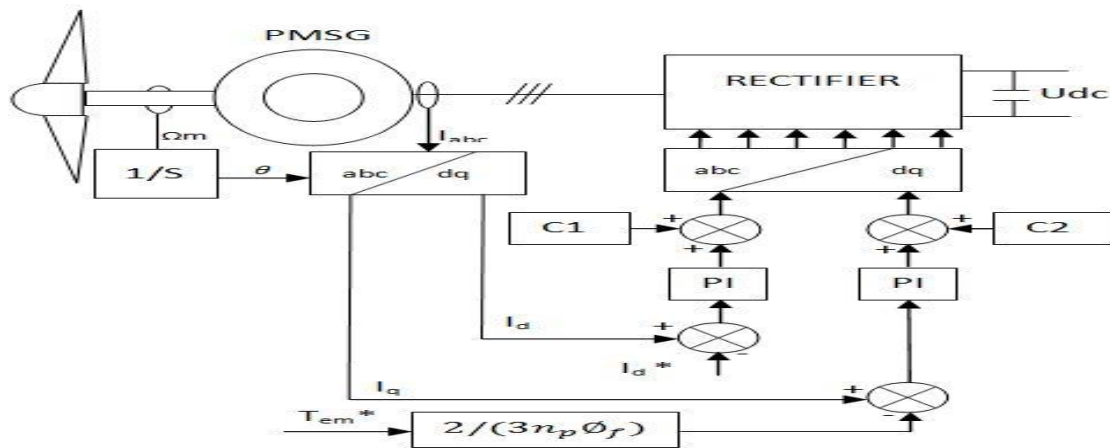


Figure 2: Block diagram of the Generator Side Control system

Where $C_1 = \omega_r L_q i_q$ and $C_2 = \omega_r L_d i_d + \omega_r \phi_r$

In the present work, due to the assumption of a fixed pitch rotor, the angle (β) is set to zero. Hence, the characteristics of C_p mainly depend on λ . Figure 3 present C_p as a function of λ . According to the figure, there is only one optimal point, denoted by λ_{opt} , where C_p is maximum. Continuous operation of the wind turbine at this point guarantees that it will obtain the maximum available power from the wind at any speed.

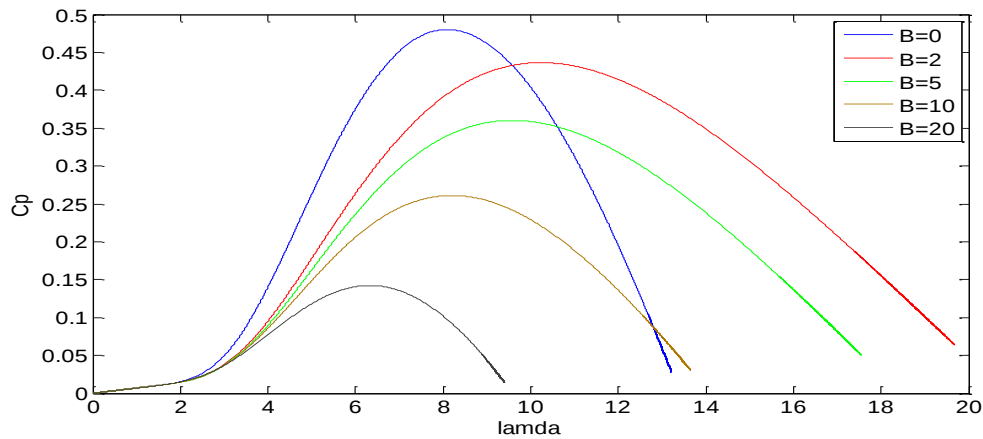


Figure 3: The C_p - λ Characteristics for different values of the pitch angle

As mentioned previously, maintaining the operation of the system at λ_{opt} ensures the conversion of available wind energy into mechanical form. It can be observed from the block diagram, represented in figure 4, that the principle of this method is to adjust the PMSG torque according to a maximum power reference torque of the wind turbine at a given wind speed.

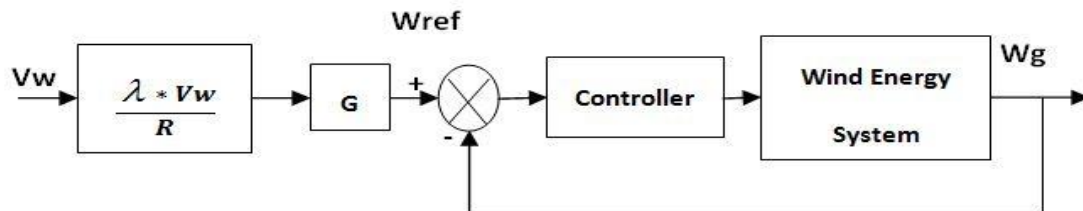


Figure 4: principle of optimal tip speed ratio MPPT method

VI. CONTROL OF THE LOAD SIDE CONVERTER

The main objective of the load side converter is to regulate the voltage and frequency.

The output voltages have to be controlled in terms of amplitude and frequency because of the absence of the grid in standalone systems.

The output voltage controller is used to control the output voltage during load transients and wind variation. The DC voltage controller maintains the dc voltage to the reference value. The control scheme is shown in figure 5.

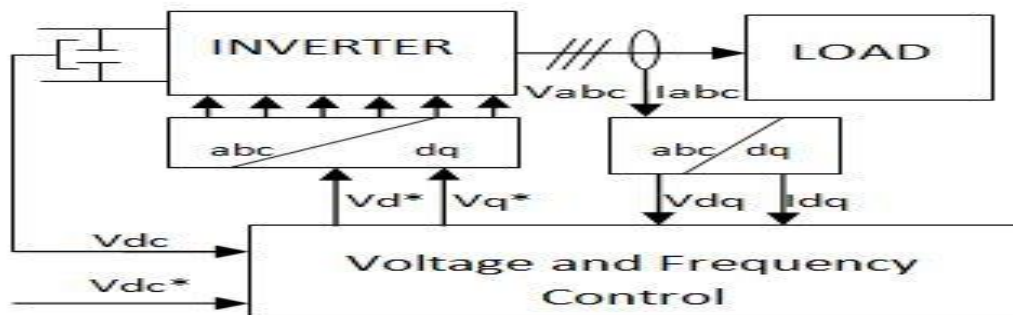


Figure 5: Block diagram of the Load Side Control system

VII. SIMULATION RESULTS

Simulations were carried out with a standalone PMSG-based WECS which has the optimal power coefficient $CP_{max} = 0.48$ and the optimal tip-speed ratio $\lambda = 8.1$

Table 1. Simulation Parameters

Parameter name	Value
Rated output power	9.4Kw
Number of pole pairs	4
Stator winding resistance Rs	0.18 Ω
Stator leakage inductance Ls	2mH
Flux	0.123
Inertia of PMSG	0.48
$C_{p\ opt}$	0.48
λ_{opt}	8.1

The Wind speed is shown in Figure (6). This is to see the performance of control strategy under variable Wind speed.

The Wind turbine with optimum power control acts as prime mover for the Permanent Magnet Synchronous Generator. The parameters of PMSG used in this paper are given in Table 1.

The rotor side converter main objectives are active and reactive power flow control and maximum power point tracking. The load side converter main objective is to regulate the DC link capacitor voltage.

Figure (7) shows the DC link voltage which is maintained at constant value at 500 V. Figure (8) shows the RMS value of the output phase voltage, where the output voltage frequency is adapted at 50 Hz. So the RMS value of output phase voltage equals 220V.

Figures (9.a and 9.b) and (10.a and 10.b) shows the output load voltage and current response, respectively. It can be seen that the control of the voltage source inverter is working well under variable Wind speed.

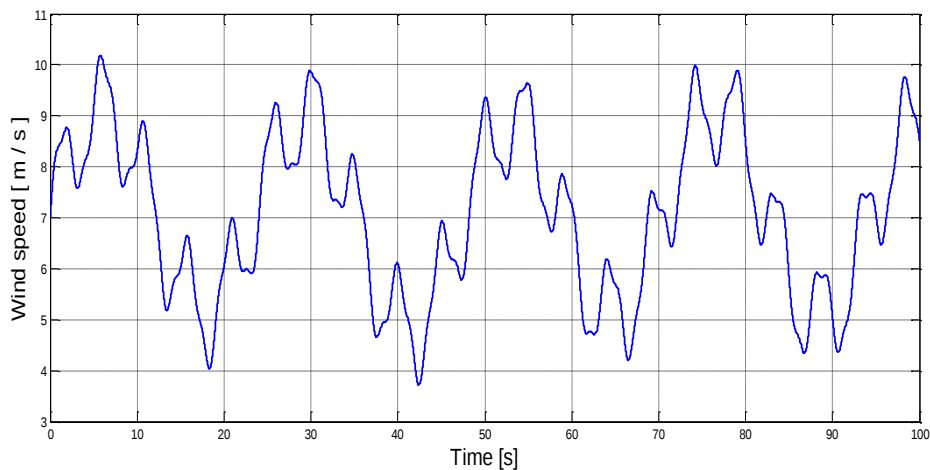
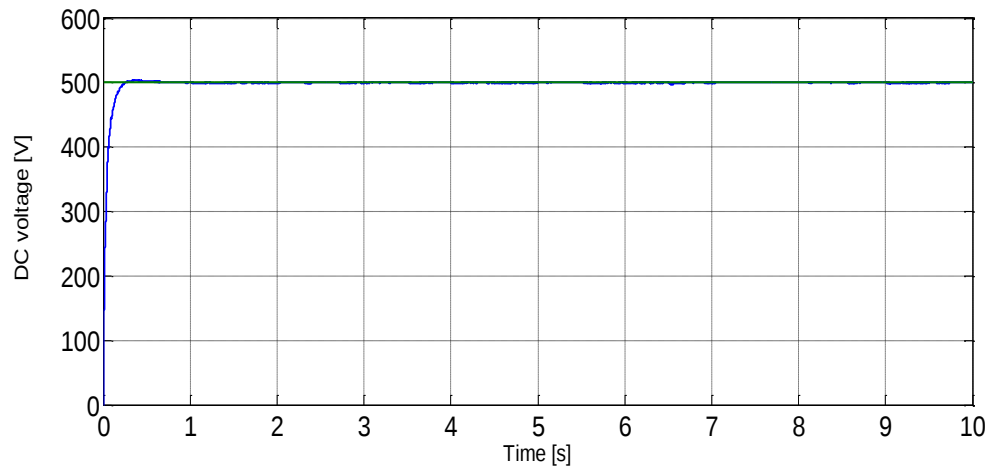
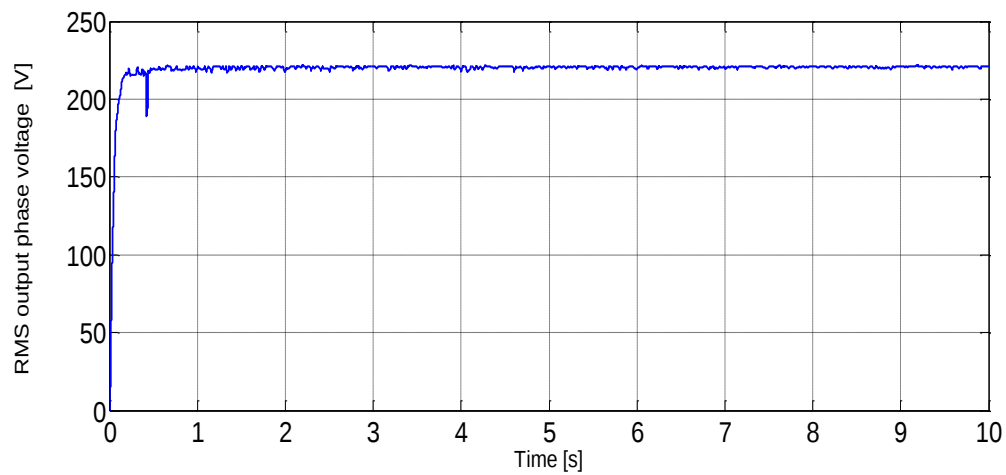
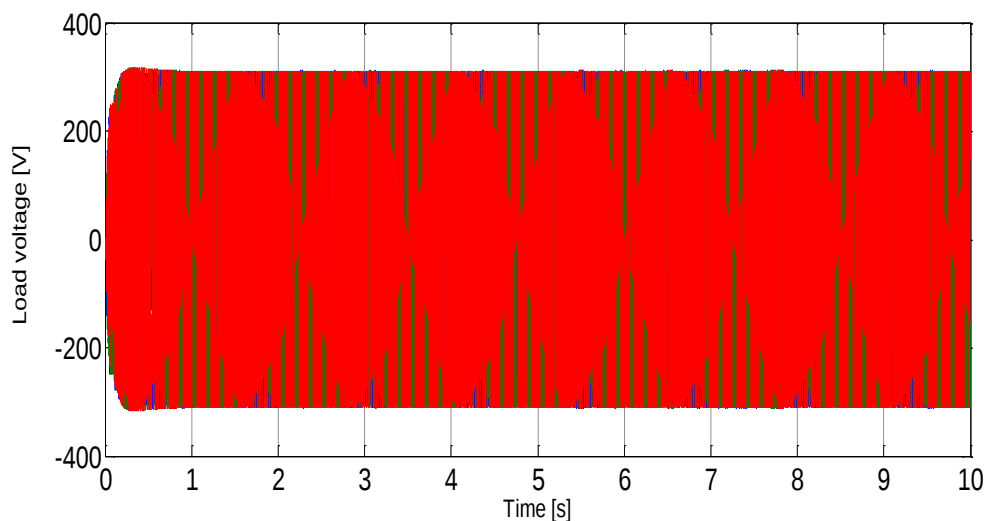


Figure 6: wind velocity

**Figure 7:** DC-Link voltage**Figure 8:** The RMS value of the output phase (A) voltage.**Figure 9.a:** Load voltage

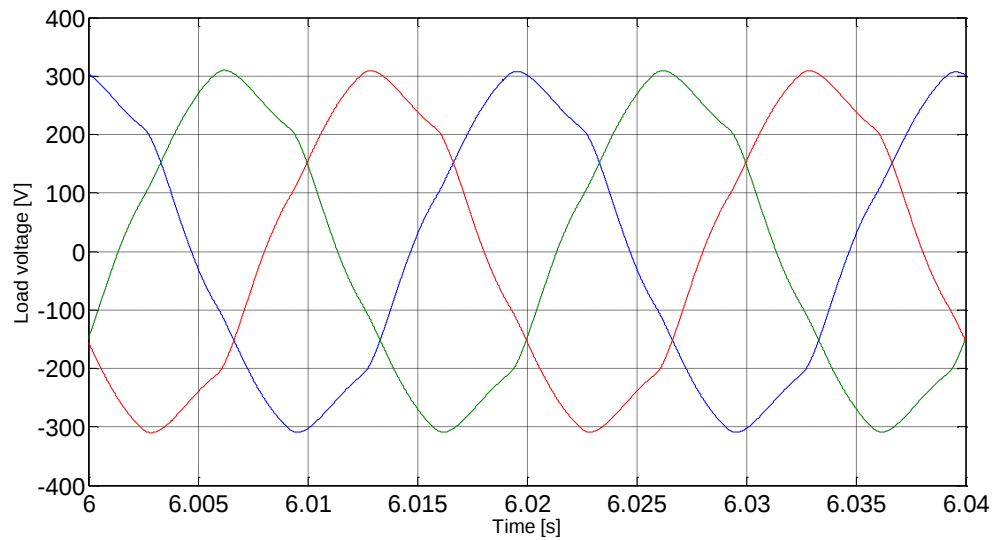


Figure 9.b: Load voltage

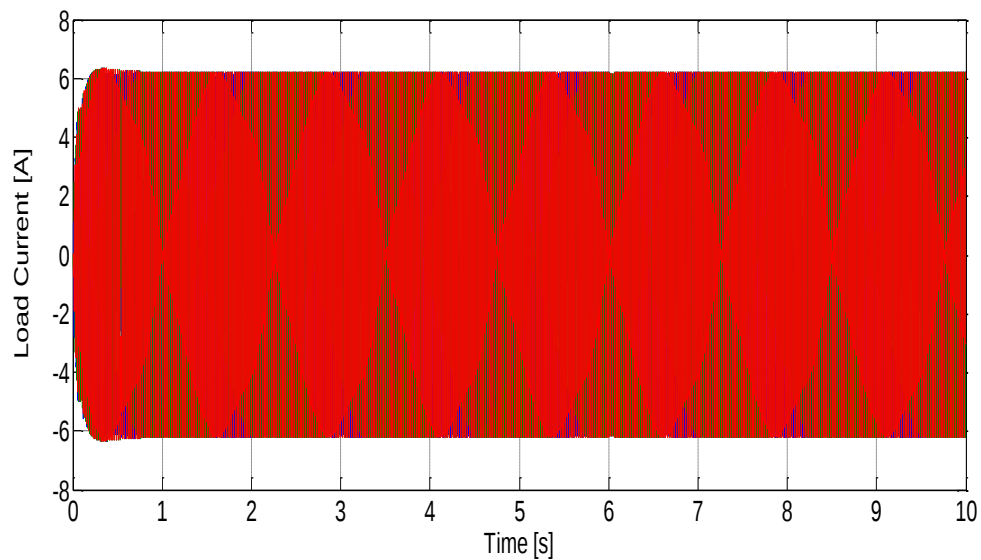


Figure 10.a: Load current

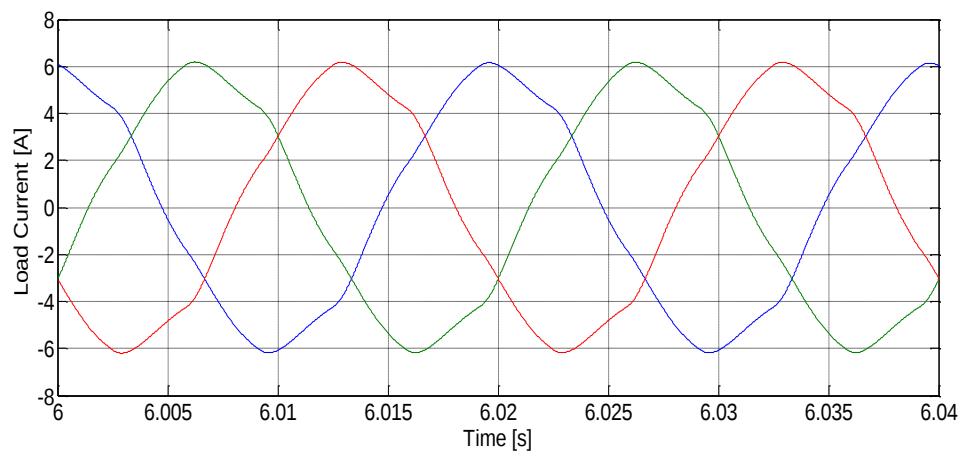


Figure 10.b : Load current

VIII. CONCLUSION

This paper presents the control of a Wind Energy Conversion System (WECS) used for the distribution of electricity for stand-alone system. A simple controller is implemented in the generator side converter to extract maximum power from the variable speed wind turbine under fluctuating wind. The DC-link voltage has been maintained at constant value.

The load-side PWM inverter is controlled using vector-control scheme to maintain the amplitude and frequency of the inverter output voltage. The simulation results show good behavior of our controllers to achieve these objectives.

As perspective, we will develop this system by adding another source (solar, storage system, etc.) and optimize the distribution of energy for remote sites. Then we will verify it by experimental work.

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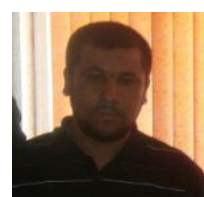
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